LITTLE BLUE BOOK NO. **603**
Edited by E. Haldeman-Julius

The A B C of the Electron Theory of Matter

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PREFACE

In writing this short account of the A B C of the electron theory of matter, it has not been found necessary to introduce any unexplained terms or ideas beyond the understanding of the average general reader. It is true that in the course of the discussion reference will have to be made occasionally to certain facts or principles which may not be familiar to those readers who have given no previous thought to the subject. But all such mentions will be made perfectly clear during the further explanations. I have thought it better to "go on with the story" without interruption, developing one phase of the subject at a time; even though a few unfamiliar terms must therefore be introduced here and there which can be more conveniently explained on pages following.

It should be understood that this little book is not intended even as an outline study of the electron theory of matter. Only a few of the many topics involved in this theory could be selected for treatment here. A sufficient number of references will be given, however, for the guidance of readers who desire to pursue the theory further.

THE A B C OF THE ELECTRON THEORY OF MATTER

I.

The electron theory of matter is, in a sense, an extension of the older atomic theory of matter.

As early as 1807, the great English chemist, Sir Humphrey Davy (1778-1829), was led to the conclusion that the forces between the chemical atoms were of electrical origin.[1] And the eminent Swedish chemist, J. J. Berzelius (1779-1848),—who instituted the system of chemical notation by symbols—shared with Davy the honor of propounding the electrochemical theory,[2] developing a system which, in its main features, has much in common with modern views on the subject.

A few years later, the laws of electrolysis (decomposition of a liquid or solution during the passage of an electric current), discovered by Michael Faraday (1791-1867)[3], led to the recognition of the atomic constitution of electricity. The conception of the electron is due primarily to the genius of Hermann von Helmholtz (1821-1894), James Clerk Maxwell (1831-1879), Dr. H. A. Lorentz and Sir Joseph Larmor. It was brought forward largely in explanation of the phenomena observed by Faraday.

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[1] *Philosophical Transactions*, Page 1 (1807).

[2] *Mem. Acad. Stockholm* (1812); *Nicholson's Journals*, Vols. XXXIV and XXXV (1813).

[3] "Experimental Researches in Electricity," Pages 377, 523, 661, 713, 821, 852 and 869. See Everyman's Library Series, Pages 48-84.

As it would be quite impossible for anyone to understand the electron theory of matter, or the principles set forth in any modern work on physics, chemistry, biology, or the problem of the origin, development and maintenance of life, without a knowledge of at least the most elementary principles of electrolysis, I must devote a few words here to this subject. Even the A B C of the electron theory of matter cannot be discussed without employing such terms as "ions", "elementary charge", etc. These terms go back to the discoveries of Faraday, leading thence to the conception of the "electron" as the elementary charge on the ion.

II.

ROLE OF THE ELECTRON IN ELECTROLYSIS

It has been found by experiment that water solutions of acids (e. g., sulphuric acid), bases (e. g., sodium hydroxide), and salts (e. g., sodium chloride) conduct electricity, and are hence called electrolytes; but such substances as distilled water, sugar, glycerine and alcohol will not conduct electricity; hence they are called non-electrolytes.

A solution of potassium chloride, hydrochloric acid, sodium hydroxide, copper sulphate, etc., readily conducts an electric current. The passage of a direct current through such an aqueous solution causes decomposition of the compounds present; whereas, as just stated, a water solution of sugar (a non-electrolyte) would not be decomposed, nor would it carry the current. The dissolved molecules of electrolytes are broken up or *dissociated* into parts, while in the case of non-electrolytes the molecules of the dissolved substance are not dissociated into these smaller parts—called *ions*, by Faraday, from the Greek, meaning "wanderer" or "traveller".

The phenomena of electrolysis were first fully explained by Svante August Arrhenius, in 1887, in terms of what is now known as the Ionic Theory. This theory satisfactorily interprets nearly all of the phenomena of *electrolytic ionization.* The ionization of gases when subjected to the action of the radiations given off by radium or to the action of the cathode rays or various similar agencies, has also played an important rôle in the development of the electron theory of matter. But this phase of the subject is not treated in the present study.[4]

In order to produce electrolytic decomposition of the molecules of compounds present in solutions, two pieces of metal, connected with a dynamo, are immersed in the solution. These are called *electrodes*, the one at which the current enters the electrolytic conductor being known as the *anode*, and the one by which the current leaves the solution as the *cathode*. The anode is often called the *positive pole*, and the cathode the *negative pole*.

When a difference of electrical potential (pressure) sufficient to cause a steady current is applied to the electrodes, chemical changes occur at both the (positive) anode and the (negative) cathode. For example, in the electrolysis of a dilute solution of hydrochloric acid, the hydrogen particles, being positively charged, are attracted to the negative pole (cathode), while the chlorine particles, being negatively charged, move toward the positive pole (anode)—bodies with electrical charges of opposite "sign" (positive and negative) naturally attracting each other, while bodies of the same sign repel each other.

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[4] See, on this aspect of the subject, Rutherford, Prof. Sir Ernest, "The Constitution of Matter," *Annual Report Smithsonian Institution*, 1915, Pages 177-173 (Washington, D. C.). See also Townsend, J. S., "Theory of Ionization of Gases by Collision."

As is well known, common table salt (chloride of sodium) consists of a compound of the poisonous metal sodium and the yellow lethal gas chlorine. Now, if we drop a pinch of this salt into a tumbler of water and stir the solution, the salt disappears, acting as if it were a gas. It dissociates into *ions* (charged particles) of sodium (positively charged ions) and chlorine (negatively charged ions). In this state the solution is perfectly neutral in reaction, since the sodium ion does not react with water. But if we now allow a direct current of electricity to pass through the solution, the positive charges on the sodium ions are immediately neutralized by the negative electrification of the cathode. The positively charged sodium ions—by taking on negative charges (electrons)—become *neutral* sodium *atoms* (the positive and negative charges now being balanced) and react with the water surrounding the cathode (negative pole), forming the typical base sodium hydroxide.

On the other hand, the chlorine ions give up their excess negative charges the moment they come into contact with the (positive) anode, neutralizing in part the charge on the negative pole (cathode). The particles (ions) of chlorine —like the particles of sodium—without their charges are ordinary neutral (electrically equilibrated) atoms, which unite *in pairs* to form *molecules* of chlorine gas, which bubbles off at the anode (positive pole).

It should be emphasized that *any* neutral atom or molecule which loses or gains an electron (negative charge) becomes an ion, or charged particle. An ion is, then, either an atom or a group of atoms carrying an electric charge. *The existence of an electric charge on an atom*—converting it into an ion—*entirely changes its properties.*

For example, chlorine *atoms* decompose water by combining with its contained (positive) hydrogen, thus setting free the (negative) oxygen. Chlorine *ions*, on the contrary, move freely about ("travel") in water without decomposing it. Again, *atoms* of chlorine, as we have seen, combine in pairs to form molecules of chlorine gas. But *ions* of chlorine repel each other, because they possess like (negative) charges. The electric charges on ions are very heavy, and their energy supply is proportionately greater than that of (neutral) atoms, and *the properties of bodies depend upon their energy supply.*

WHAT CONSTITUTES AN ELECTROCHEMICAL REACTION

From what has been said, it will be understood that in any solution of electrolytes *all* of the anions (negatively charged particles) travel toward the anode (positive pole or electrode), while *all* of the cations (positively charged particles) moved toward the cathode (negative electrode). It is the movement of these ions which constitutes the current of electricity through the solution (as though there were a stream of electrons flowing along a copper wire—the electrolytic solution taking the place of the metal conductor).

The *direction* of the current in the solution is arbitrarily defined as the direction in which the cations (positively charged particles) move —which is opposite to the direction of the electron stream but in the same direction as the positive current entering the anode.

Generally speaking, every species of ion in the solution, no matter how great a number of kinds of ions there may be, helps in carrying the current. But since each species helps only in proportion to its current-carrying capacity (i. e., in proportion to its numbers, the charges which it carries, and the velocities with which it moves), in conducting the current *from* the solution *to* the electrode, or *vice versa*, only a few, and in many cases only one species of ion is involved; namely, that species which most easily takes on or gives up an electron under the conditions. The exchange of electrons between the solution and the surface of the electrode constitutes an *electrochemical reaction.*

When an electrolyte is dissolved in water, not all of its molecules are dissociated; but the molecules which do separate into particles become electrically charged in the process, *by taking on or giving up electrons.* Subtraction of a negative electron from a neutral atom is equivalent to adding a positive charge. The chemical changes which occur at the surface of the electrodes are the result of the taking on or giving up of electrons not only by single atoms, but by *groups of atoms*, which may, in this case, be regarded as ions. For every ion involved in this electrochemical process, one, two, three or four electrons are involved, according as the ion carries one, two, three or four charges which must be neutralized.

III.

THE MEANING OF "VALENCE"

The number of charges carried by an ion depends upon its combining power, or *valence*—i. e., the number of atoms of other elements with which it combines. The hydrogen atom is the standard of valence.

For example, the hydrochloric acid molecule consists of one atom of hydrogen and one atom of chlorine, the simplest combining relation possible. The valence—combining power—of each of these elements is one, or "unity," and they are therefore known as *univalent* elements. Their ionic charge would therefore be *one electron.*

One atom of oxygen unites with two atoms of hydrogen; so the valence of oxygen is two—i. e., it is *bivalent.* In the case of ammonia, NH^3, one atom of nitrogen is combined with three atoms of hydrogen; hence, in this compound, nitrogen has a valence of three; hence also, it is *trivalent.* Marsh gas, CH^4, contains four atoms of hydrogen combined with an atom of carbon; carbon, therefore, has a valence of four; it is *quadrivalent.* In short, the valence of an element is the number of hydrogen atoms with which its atom will unite (or which it will replace[5]).

In electrolytes, then, the valence of each ion is numerically equal to the number of charges carried by it. This indicates an intimate connection between the valence and the electrical capacity of an atom.

IV.

COMBINING WEIGHTS

We speak also of the *combining weights* of substances—i. e., what weights of substances are needed for a given chemical action. Each element enters into chemical action in a definite number of parts by weight. If we base these numbers on a relative scale, the number for an element is the same in all its compounds. This number is called the *equivalent* or *reacting weight* of the element. The number is found by determining the number of *parts by weight* of the given element which will unite with, or replace, one part of hydrogen (whose equivalent weight is 1), hydrogen being thus taken as unity.

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[5] For example, an atom of calcium will replace two atoms of hydrogen in hydrochloric acid, and unites with two atoms of chlorine. Hence calcium is bivalent.

FARADAY'S LAW OF ELECTROLYSIS

Now, it has been found that for every electrochemical change *involving one equivalent weight* of a substance, the same quantity of electricity will always be required. Each chemical atom invariably transports either a definite quantity of electricity (equivalent to the charge on an electron), or an integral (simple) multiple of that quantity—a multiple determined by the chemical valency (combining weight) of the atom. The unit or elementary charge (quantity of electricity) never increases by a fraction of itself, but is augmented by each additional ionic charge; that is to say, according as the change in valence is one, two three or four units, which we now know to represent the addition to the ion of an equal number of electrons—the elementary charge of electricity—*the atom of electricity.*

This conception of electrical atomic charge on the atom was advanced by von Helmholtz as long ago as 1881,[6] on the basis of the electrolytic researches of the immortal Faraday.

Already, in 1833, Faraday had formulated his *Law of Electrolysis*, which states, in words (to avoid the mathematical equation), that whenever an electric current passes across a junction between a purely metallic and a purely electrolytic conductor, a chemical change or chemical changes occur, the amount of which, expressed in chemical equivalents, is *exactly proportional to the quantity of electricity which passes and is independent of everything else.*

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[6] In his famous "Faraday Lecture."

The amount of electricity required to produce one equivalent of chemical change is known as one faraday.[7] The value of the faraday has been very accurately determined, and this achievement has led to great advances in the electron theory of matter.

V.

ELECTRICITY AND ELECTRONS

When we speak of a "current of electricity" we are really referring to a flow of *electrons* along the conductor, for the electrons are the atoms of electricity, just as the smallest possible portions of the metal gold or of the gas hydrogen are the chemical atoms of these elements. But while the "atom" of the elements is *matter* as commonly understood, the atom of electricity is not matter in the ordinary sense of the word. Nor is the positive charge, which constitutes the core or nucleus of the chemical atom, matter.

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[7] Cf. Washburn, Prof. Edward W., "Principles of Physical Chemistry," Pages 242-246, New York, 1921.

Matter does not exist until at least one electron revolves around one *proton*—as the positive electron has come to be called. Then we have an atom of the gas hydrogen—the lightest and simplest of the elements: *Two oppositely charged electrons which separately are not matter become matter when one revolves around the other!*

But all of the 87 known different kinds (species) of atoms (of the theoretical 92 supposed to exist) contain nothing but (negative) electrons and (positive) protons, presumably all precisely like the two kinds of electrons in the hydrogen atom. Hence the atoms of the gases hydrogen and helium, etc., are made up of the same constituents as compose those of the atoms of, say, radium, sulphur, gold, etc.

But while we may properly speak of the negative units of electricity (electrons as "point charges of disembodied electricity and nothing else" (Sir Oliver Lodge), nevertheless we need not look upon electrons as being *immaterial.* If they are not material, then they are metaphysical, and physicists are not usually metaphysicians. Moreover, metaphysicians do not *weigh* and *measure anything*, and electrons have been weighed and measured. Dr. Robert A. Millikan tells us that we may, with perfect justice, speak of these electrical specks which "journey along the conductor" as "definite material bodies".

Professor H. A. Rowland (1848-1901), of Johns Hopkins University, long ago (1876) showed that an electrical current is nothing but a series of electrical charges in motion (see *Ann. der Physik.*, Vol. CLVIII, Page 87, 1876); hence the electrical current that flows through an arc light is merely the movement of a definite (countable!) number of these atoms of electricity through or over the filament of the lamp.

Now, as Dr. Millikan puts it, "the only distinguishing property of matter is *inertia*".[8] The mass of ordinary matter is probably nothing else than the electromagnetic mass of its contained electrons, as was first suggested by Prof. Larmor (*Phil. Trans.*, Vol. CLXXXVI, Page 697, 1895).

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[8] Millikan, Dr. Robert A., "Modern Physics." In "Contemporary Science," Page 16, New York, 1921.

MASS AND INERTIA

Inertia, or mass, is a quality which was formerly regarded as belonging only to matter—the property by which a body at rest cannot be set in motion without the application of force, and cannot be stopped or made to go faster or slower without the application of force. "Mass", or inertia, was previously thought of as equivalent to "quantity of contained matter", since the weight of all bodies is proportional to their mass.

J. J. Thomson demonstrated, in 1881,[9] that an electric charge possesses inertia. Hence, to quote Dr. Millikan, "it is perfectly legitimate to say that an electrical current in a wire is a definite, material, granular something which is moving along that wire."

Since electricity possesses inertia, it must also possess mass, if not "weight" in the ordinary sense; for although its mass is all electromagnetic, it cannot be moved from rest, nor be brought to rest if moving, without an expenditure of energy, and it is in this sense that we must regard the disembodied electron as having inertia or mass—"the only distinguishing property of matter".

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[9] *Philosophical Magazine,* V, Vol. XI, Page 229 (1881).

But mass and inertia are equivalent to energy, and the equivalence of mass and energy can be easily deduced. It can readily be shown that $9x10^{10}$ ergs of energy must be the equivalent of one gram of mass.[10]

In his monograph on "The Electron" (1917), Dr. Millikan illustrates the minuteness as well as the vast numbers of electrons involved in electric phenomena by stating that the quantity of electricity which courses *every second* through a common 16-candle-power electric-lamp filament is so large that if two and a half million persons were to begin to count out these electrons, and were to keep on counting them out, each at the rate of two a second, and if no one of them were ever to stop to eat, sleep or die, it would take them just 20,000 years to finish the task!

The number of electrons which would flow through an ordinary 10-ampere arc-lamp in two hours and 41 minutes is put by Professor Soddy as, roughly, $7x10^{23}$.[11]

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[10] The *erg* is the Centimeter-Gram-Second System unit of work and energy=1 dyne acting through 1 centimeter; 1 dyne being that force which acting for 1 second on 1 gram produces a velocity of 1 centimeter per second. One gram=0.0352 ounce. Hence there are 28.349 grams in 1 ounce (averdupois).

It is now well established that in metallic substances some of the electrons are able to move about from atom to atom within the body of the metal with comparative ease. But no electric current (stream of electrons) is set up in a piece of metal until a "difference of potential" (pressure) is applied to the ends of the metal; just as gas or water will not flow through a pipe unless there is a higher pressure at the source than at the terminal.

As is well known, if two gas bags, containing gas at different pressures, are connected by a pipe, the gas will flow from the bag where the pressure is high to the one where it is low until the pressure is the same in both. In the same way we may regard "potential" as measuring the electrical pressure of the charge.

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[11] When values are very large, it is not customary for scientists to write them out, but use is made of what is known as "the positive index." For example, instead of writing out three billions as 3,000,000,000, the algebraic notation $3x10^9$ is given, the small figure above the 10, called the exponent, indicating the number of times 10 is taken as the multiplier. Thus in order to idicate six trillions (6,000,000,000,000) one need only write $6x10^{12}$. In the case above it would be necessary to write down 7 followed by 23 ciphers. The notion for smaller values runs as follows: 10^0= 1; 10^1=10; 10^2=100; 10^3=1000; 10^4=10000; and so on.

Electricity will not flow from one place to another at the same potential, no matter what the charges may be.

The increase of temperature which is always produced by the passage of the stream of electrons through a conductor is caused by collisions of the swiftly flowing electrons with the atoms of the metal. The strength of the current for a given difference of potential varies with the nature of the metal and with the temperature, the strength of the current increasing as the temperature of the conductor is lowered, becoming apparently infinite at the absolute zero.

When electrons flow through a metal—passing from atom to atom—there occurs not only what we call an electric current, but a magnetic field—"lines of force"—is set up at right angles to the current—encircling the conductor—and the direction and nature of the field are always the same whether the current in the metal is caused by the motion of what is called positive electricity in one direction or by the motion of negative electricity in the opposite direction. Even a single electron in motion creates a magnetic field around its path.

The terms "positive" and "negative" electricity were introduced by Benjamin Franklin, about 1756. Electricity was then (and for many years thereafter) regarded as a fluid which passed through a conductor much as water through a pipe. Bodies with an excess of the "fluid" were said to be positively charged, while an undercharged body was said to be "negative".

As is well known, if a piece of glass is rubbed with a piece of silk under suitable conditions, they will attract one another; while two pieces of silk or two pieces of glass repel one another. It was therefore assumed by many physicists that there are two different kinds of electricity, and the name "positive" electricity was arbitrarily chosen to represent the "glass-electricity" and "negative" for the "silk-electricity".

In Franklin's day, and until quite recent times, the "direction of the current" in a metal was arbitrarily defined as the direction in which "positive" electricity would have to flow in order to produce the observed magnetic effects. But, as we have just seen, the current is really due to the motion of negative electrons producing negative electricity. Nevertheless, electricians still use the old nomenclature, and, paradoxically enough, define the "direction of the current" in a metal as the direction *op-*

posite to that in which the electricity actually flows.

VI.

SIZE OF ELECTRONS AND ATOMS

The reader who is not already informed on the subject will naturally desire to obtain some idea of the shape, size and weight of electrons and atoms. As to the form of the electron, this is a question which no man can answer, since there is no method by which this problem can be solved. And there is room for an enlightened difference of opinion as to the size of electrons.

If the electron is spherical, which is the assumption of nearly all physicists, we may say that its diameter is certainly not more than one five thousand billionth of an inch (=1/5,000,000,000,000); and it may be considerably smaller. In other words, it would require at least five trillion electrons, placed side by side, to make a row of them one inch in length.

The mass (weight) was first directly ascertained by Dr. Robert A. Millikan, by means of an ingenious electrical balance, able to detect a mass down to one two billionth of a milligram; and a milligram is less than one thirty thousandth of an ounce. The electrical *charge* on the electron turned out to be $4.774x10^{-10}$ electrostatic units, which is equivalent to a *mass* **if** $9.01x10^{-28}$ gram.

The electron weighs about 1845 times less than an atom of hydrogen—the lightest known —or $1.662x10^{-24}$ gram—about one eleven octillionth of an ounce—a million million times less than the smallest visible speck of puff-ball dust (lycopodium spores), the lightest mass that can be weighed on a very delicate chemical balance (Lodge). Fournier d'Albe calculated that the number of electrons in the human body would be represented by ten raised to the 31st power —10x30 zeroes.

The *atomic weight* of an element gives, according to the highest authorities, the number of electrons of all kinds (planetary electrons and *nuclear* (binding) electrons and protons (positive charges) in each species of atom. But we can go much farther, because one gram of any kind of substance always contains the same number of electrons, namely, $6.05x12^{23}$. Now the mass of the earth is known, and expressed in grams it comes to $5.984x10^{27}$. If this is multiplied by the number of electrons per gram, we obtain the number of electrons in the earth; namely, $36.2x10^{50}$.[12]

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[12] Cf. Crehore, Dr. Albert C., "The Mystery of Matter and Energy," Page 132, New York, 1917.

Calculating their dimensions from their mass, Rutherford assigns to the average atom a diameter ("sphere of action") of one one hundred millionth of a centimeter; while the diameter of an electron, considered as a sphere, is about 10^{-13} cm., and of the nucleus about 10^{-12} cm. About five million atoms of helium (which stands next to hydrogen in atomic weight) could be placed in a line across the diameter of the "period" at the end of this sentence. The number of atoms of helium in one cubic centimeter of that gas at normal pressure and temperature is 2.75×10^{19}.

The number of atoms in a cubic centimeter of water, according to Prof. Duncan MacMillan, "is something like 3×10^{22}". But the number of atoms in the solar system, he tells us, is "something like 6×10^{55}". We may add that of these atoms more than 99% go to form the sun. To be exact, 99-6/7% of the material of the entire solar system is in the sun, and only 1/7 of 1% is divided up to form the planets, satellites, asteroids, comets, meteors, etc.

In a cubic inch of air there are about 43 billion billion (=43,000,000,000,000,000,000) molecules—a molecule being the smallest amount of any substance or compound that can exist in a free state. The molecules of all the common gaseous elements contain two atoms. In the case of some elements, for example mercury and zinc, one atom constitutes a molecule. Phosphorus, on the other hand, has four atoms to the molecule; sulphur eight, six or two, according to the temperature.[13]

Molecules of the various elements vary in size, while those of some compound substances —starch, for example—may be enormously large compared with the molecule of water. But it represents the facts closely enough to say that the average molecule of matter is less than 1/125,000,000 of an inch in diameter. The diameter of the hydrogen atom, the smallest of all, is about a hundred thousand times larger than the diameter of the electron—or, at the most, one hundred millionth of an inch (1/100,000,000).[14]

"If the earth were made up of baseballs," says Comstock and Troland, "it would be a fair model of a drop of water made up of atoms".

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[13] We owe the distinction between atoms and molecules to the long obscure Italian chemist Avogadro (1776-1856), who, in 1811, explained certain anomalies in Gay-Lussac's Law of Volumes by introducing the concept of the molecule.

[14] According to Dr. John Cox, "the electron is about three times as small compared with the hydogen molecule (atom), as the earth is compared with the diameter of its orbit round the sun." See his "Beyond the Atom," Page 127, Cambridge University Press, 1913.

Calculations "from coefficients of expansion" have led some investigators to the conclusion that "the sizes of different kinds of atoms are in the same order as their weights". The uranium atom (atomic weight 238.2) is usually thought to be about two and a half times greater in diameter than the hydrogen atom (atomic weight 1.008).

Someone has estimated that about six million hydrogen atoms could stand on the point of a sharp needle. The largest atom, as just stated, is that of uranium; but it is quite certain that nearly a million of them, "single file," could find room on the diameter of a hair from the head of a human being. The diameter of the nucleus (proton) of the hydrogen atom is not certainly known, but it is thought to be of the order of one two thousand billionth of an inch (1/2,000,000,000,000).[15]

An average *molecule*—say a molecule of dye—has a diameter about one three thousandth the thickness (or rather thinness) of the page upon which these words are written. And a molecule of water is much smaller than a molecule of any dye. The film on the surface of a soap-bubble is less (at the dark spots) than one three millionth of an inch thick, and physical considerations indicate that the molecules must be from twenty to thirty times less in diameter than the film. Professor Perrin measured films of oil down to the fifty millionth of an inch in thinness, and experiment showed that even this was at least two molecules in depth. From this it has been deduced that a molecule of oil is one one hundred millionth of an inch in diameter. "The smallest particles visible under the microscope," says Prof. Frederick Soddy, "contain millions of separate molecules."[16]

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[15] For a full explanation of how the diameter of the nucleus of atoms is determined, as also the dimensions of the atom itself, see Rutherford, Prof. Sir Ernest, "The Constitution of Matter and the Evolution of the Elements," Annual Report Smithsonian Institution, Pages 167-202, Washington, D. C., 1915.

VII.

STRUCTURE OF ATOMS

Most modern physicists visualize an atom of oxygen, for example, as somewhat similar in structure to our solar system. The sun may be represented as the nucleus, and the principal planets by the eight negatively charged electrons which revolve in circular or elliptical orbits around the positive charge (proton) in the center—which is analagous to the sun. If we think now, for convenience of illustration, of an atom of hydrogen, which has but one planetary electron and one proton (one central positive electron or "charge"), the size of the orbit of the one negative revolving electron is comparable to the size of the earth as compared with the orbit of Neptune, the farthermost known planet, revolving at a distance of nearly 3,000 million miles from the sun.

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[16] Cf. Perrin, Prof. Jean, "Atoms," Authorized Translation by D. L. Hammick, 2nd Eng. ed., revised, London, 1923; "*Atomes et Electrons Rapports et Discussions du Conseil de Physique,*" Etc., Paris, 1923; Soddy, Prof. Frederick, "Matter and Energy," London and New York, 1912.

But whereas the sun is 1,300,000 times larger than the earth, the positively charged nucleus of the hydrogen atom is, as we have seen, probably no larger than the planetary negative electron, and is believed by some authorities to be much smaller.[17]

Just as the more complex atoms are comparable in structure to our solar system, the atom of hydrogen, with one nuclear positive charge and one revolving (negative) electron, may be said to be analogous to the earth-and-moon system. Then an atom—any atom—is mostly *empty space!*—for the distances between the nucleus (or core) and the orbits of the revolving negative electrons in atoms are comparable to the distances of the orbits of the planets from the sun and from each other, considering the size of the atoms themselves. But whereas in our solar system only one planet travels in a single orbit, which it never leaves, in the more complex atoms several negative electrons travel in virtually the same orbit or zone, forming in some cases a procession of eight electrons.

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[17] Cf. Mills, John, "Within the Atom," London, 1922; Stewart, Prof. A. W., "Some Physico-Chemical Themes," London, 1922; Rutherford, Prof. Sir Ernest, *Loc. Cit.;* Stock, Prof. Alfred, "The Structure of Atoms," London, 1923.

Moreover, the planetary electrons do not "stay put". They change from one orbit to another; and it is during this "jump" that energy is absorbed or radiated—setting up electromagnetic waves in space, in the form of Hertzian (wireless), heat or light waves.[18]. This theory is in harmony with Planck's "quantum theory of light", which assumes that in the emission of radiant energy by an oscillating atom or electron (the *resonator*), this energy is radiated in discrete units or pulses called *quanta*.

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[18] Cf. Bohr, Prof. Niels, "The Theory of Spectra and Atomic Constitution," Cambridge University Press. 1922. Also, Planck, Prof. Max, "The Origin and Development of the Quantum Theory," Oxford (Clarendon Press), 1922.

We must now refer briefly to certain lines of inquiry not previously mentioned, which led up to the theory that atoms—all forms of matter—are composed of minute geometrical configurations of electric charge (electrons), instead of the uncharged "atoms" of the older chemical theory.

VIII.

DISCOVERY OF ELECTRONS

It was in 1877 that Sir William Crookes (1832-1919)—discoverer of the element thallium, inventor of the radiometer, and the man to whom we are indebted for a considerably improved air-pump—turned his attention to the phenomena attendant on the passage of the electric discharge through a vacuum tube—"Crookes' tube"—from which air had been so thoroughly pumped that only about 10^{-7} of atmospheric pressure remained.[19]

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[19] When values are very small, as is frequently the case in the study of electrons, atoms and molecules, it is not customary to write them out, but use is made of what is known in mathematics as "the negative index." The value given above =0.0000007 of an atmosphere. Again, 10^{-1}=0.1, or one tenth; 10^{-2}=0.01, or one hundredth; 10^{-3}=0.001, or one thousandth, and so on: so that instead of having to write out so small a value, as, say, 0.000000000000001, one simply writes 10^{-15}, the index number showing how many decimal places are indicated.

When the electric current is switched on, the negative pole (cathode) of the evacuated tube emits the now familiar *cathode rays.* These radiations are projected with great velocity at right angles to the surface of the cathode, and travel in straight lines, like light rays, whatever may be the position of the anode (positive pole)—giving rise to phosphorescence of the glass tube by a veritable bombardment by the rays.

There was nothing new in Crookes' experiment, for Pluecker had previously described the phosphorescent glow that appears when the current of an induction coil is passed through a sufficiently exhausted vacuum tube. He had also observed the very significant fact that, unlike light, the cathode rays are deflected from their normal path, under the influence of a magnet. Hittorf had noticed that a shadow is cast by a solid body placed between the cathode or negative pole and the seat of the phosphorescence.

Crookes, in the course of his experiments, discovered that, by employment of a concave cathode, the rays could be focussed directly on an object. He found that a piece of platinum under the treatment soon becomes red hot, and may even be fused. He found further that in a device known as the "railway tube" the rays drive a wheel along glass rails. He discovered further that when the rays were focussed on certain substances, and in particular on such gems as diamond and ruby, the jewels exhibited a brilliant phosphorescence.

CROOKES' INTERPRETATION

The point of special interest is Crookes' explanation of all these phenomena. With characteristic devotion to truth and indifference to conservative opinion, this brilliant physicist and chemist advanced the hypothesis that the cathode emits *material particles.* These minute corpuscles are deflected by a magnetic field because they carry a charge of negative electricity.

The rays were regarded as *material*, but not in the ordinary sense of the word, for the radiation was neither gaseous, liquid nor solid. Hence he classified them as representative of "a new or fourth state of matter", as far removed from that of gas as gas is from liquid, a state of matter where the familiar properties of gases and elastic fluids disappear, and in their stead are revealed new and unsuspected attributes.

While it is true that the cathode rays are not gaseous, modern opinion regards the negative electrons in a conductor as in a condition very similar to that of the molecules of a gas.

J. J. Thomson tells us that "these corpuscles are the same however the electrification may have arisen, or wherever they may be found. Negative electricity, in a gas at low pressure, has thus a structure analogous to that of a gas, the corpuscles taking the place of the molecules. The 'negative electric fluid,' to use the old notation, resembles a gaseous fluid with a corpuscular instead of a nuclear structure."

But whatever their structure or physical properties may be, Crookes felt that here, at last, mankind had within its grasp the primordial element of the Universe, vainly sought for by the ancients. For these rays he supposed to be made up of a succession of the minute, indivisible, primitive particles postulated by the Atomists, the ultimate units of matter, *perhaps of life itself.* Moreover, Crookes did not hesitate to declare his conviction that, in the last analysis, *matter is a form of electricity!*—a conclusion concurred in by the late Lord Rayleigh.[20]

ISOLATION OF THE ELECTRON

For 19 years a rather fruitless controversy was waged over Crookes' explanation of the nature of the cathode rays; when, in 1897, Prof. E. Weichert[21] in Germany, and Prof. J. J. Thomson[22] of Cambridge independently discovered methods for conclusively demonstrating the nature of these hitherto mysterious rays. Their experiments proved, as Crookes had surmised, that the radiation consisted of a stream of negatively charged corpuscles, travelling with velocities of from 10,000 to 100,000 or more miles a second, depending on the electrical potential (or pressure) applied to the vacuum tube.

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[20] It is interesting to note that Lord Rayleigh—later Chancellor of Cambridge University—was like Crookes, deeply interested in psychic research. Crookes is the author of a well known book on spiritualism in which he records remarkable experiences of his own. A writer in *Nature* (London), at the time of Crookes' death, well remarked that a man of his temperament and his remarkable independence of view in regard to the range of scientific inquiry and the proper attitude of the scientific investigator would naturally be led to look attentively at subjects of all kinds, some of which might be regarded as suspect by other people."

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[21] *Verhandlung der Physik.-oehon. Gesellschaft. zu Koenigsberg, i. Pr.* 1897).

[22] *Philosophical Magazine,* V. Vol. XLIV, Page 298 (1897).

Two other predictions of Crookes also have either been fulfilled or are in a fair way toward verification: namely, (1) his provisional conclusion that the so-called elements are in reality not homogeneous, but mixtures; and (2) that the heavier elements are formed by a process of combination and condensation from the lighter elements, all being derived, ultimately, from *one homogeneous primordial stuff,* to which he gave the name "protyle". I think it is not too much to say that the first supposition has, in fact, been verified, both by the disintegration products of radio-active substances and by the "mass spectrum" obtained by the positive-ray spectograph of Dr. F. W. Aston,[23] physicist in the Cavendish Laboratory, Cambridge University.

The second assumption of Crookes, that the elements are all derived from one primordial substance (or species of atom), is daily gaining adherents among physicists and chemists. While it was generally assumed that the chemical atom of Higgins and Dalton was the ultimate particle of matter, an indivisible unit, nevertheless Sir Humphrey Davy (1778-1829), William Prout (1785-1850), Michael Faraday (1791-1867) and others suspected that these extremely minute—and as yet merely hypothetical—bodies might some day be "decomposed" by chemical or physical processes. As early as 1815, Dr. Prout, an English physician, advanced the hypothesis that all the elements were made up of *hydrogen atoms*—a view discordant with the "facts", as then known, but which has recently been revived in the light of further advances. Dumas (1800-1884) suggested that the ultimate atom might be a particle one-half or one-quarter the mass of an atom of hydrogen. Thomas Graham (1805-1869) in 1863 suggested that the various kinds of matter, or different elementary substances, were all composed of the same unit atomic corpuscle, and that the differences in substances were due to different conditions of movement of the ultimate atoms, "taking various forms by combinations unlimited." He concluded that "by separation and union with constant motion all things could be done".

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[23] See his "Isotopes," London, 1922. See also Soddy, Prof. Frederick, "The Chemistry of the Radio Elements," 1911-1914; Thomson, Sir J. J., "Rays of Positive Electricity and Their Application to Chemical Analysis," London, 1914.

The hydrogen atom, consisting of one negative and one nuclear positive electron, is now believed by most physicists to be the element from which all the more complex atoms are built up. Since all the outlying negative electrons in all atoms are eactly alike—as far as is known—it is safe to assume that the opposite and equal charges on the nucleus, which we designate as positive electrons (or protons), are all alike.

Two of these same negative electrons held in their orbits or positions by two positive electrons (or equivalent charges on the nucleus) constitute an atom of the gas helium. All the 87 known elements—theoretically there should be 92 in all—are successively built up by the addition of one extra outlying negative electron and one additional (or equivalent) positive charge (proton) on the nucleus. Disrupt, say, a nitrogen atom, containing seven negative electrons and seven positive charges, and out comes an atom of helium. The contained atom of hydrogen—the very core of the nitrogen and all other atoms—in this case (Rutherford's experiment) remains, apparently, intact in the nucleus. We may, then, tentatively at least, regard hydrogen as the primordial *atom.*

Crookes' cathode rays (electrons), along with the nuclear positive electrons (or protons), are the primordial *stuff* of the Universe. Here, at last, is the answer to Thales, Anaximander, Anaximines, Heraclitus and the other early Greek physicists.

In making the foregoing assumptions, I am not unmindful of the fact that, for example, neither hydrogen nor oxygen has any of the properties of water, yet we designate that fluid as H^2O. What we really mean is that H and O are always atomic *products* of the disruption of a molecule of water, but they certainly are not *identical* with that still mysterious fluid. And just so electrons, or electricity, may possibly be products of the disruption of matter, and yet not be *identical* with matter, or even with *mass*. Much yet remains to be learned in the domain of physical chemistry.

IX.

ORIGIN OF ELECTRONS

As for Crookes' view that all matter is electrical in nature, there are not, so far as I know, any physicists living to-day who doubt the truth of this theory of the constitution of matter.

Crookes, as we have seen, assumed that the cathode rays are material in nature, true matter, but in a hitherto unknown state. Lodge regards the electron as "a point charge of disembodied electricity, and nothing else", the flying or vibrating corpuscle being a constituent of the atom of the chemist but possessing itself no material nucleus.

As we have seen in the statement of Millikan quoted above, he tells us that "the negative electron is nothing but a disembodied electrical charge", yet this does not mean that he looks upon the negative electron as an immaterial entity. He states in the same lecture that "the thing we call electricity is built up out of a definite number of specks of electricity, all exactly alike; and what we call an electrical current consists simply in a journey along the conductor of these electrical specks, which we may call with perfect justice definite *material* bodies."

Only a short time ago, Sir Oliver Lodge, like most physicists, felt quite confident that both the negative electron and what has come to be known as the proton were built up "out of the ether of space", though he has always been quite willing to concede that this electron-building was by some unknown process. He still thinks that this is probably their origin, "so that they need not be foreign bodies in the ether, but a specifically organized portion of it." He adds that "all this is at present hypothetical and need not be emphasized. Suffice it for present purposes to say that both electron and proton certainly exist; and almost as certainly that they constitute the apparently indivisible elements of which all matter is composed."[24]

Faraday thought—and the majority of physicists still think—that the "lines of force" from what we call electrically charged bodies were due to modification in a surrounding "ether".

Dr. Norman R. Campbell, England's foremost electrical engineer, like the late Dr. Charles P. Steinmetz, thinks that "it is sensible to say that the lines of force are made of anything, only when we can imagine their being made of different things; *lines of force are just lines of force*, independent for their existence of all surrounding bodies, and there is no more to be said about them. . . . If lines of force passing through sulphur are not made of sulphur, there is no need, when the lines pass through a vacuum, to imagine the vacuum filled with a substance of which the lines may be made; in other words, our electrical theory, so far from providing additional support for the conception of the ether filling all space, does not require such a conception at all. All it needs is the conception of lines of force; where there are no lines there is no need of anything at all. We do not require to imagine present everywhere a substance of which the lines of force may be made when charged bodies come into the neighborhood, for the bodies bring their own lines within them, ready-made and unalterable."[25]

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[24] "Within the Atom," *Scientific American,* Page 308, December, 1923.

X.

IS THE ETHER A MYTH?

Can we abandon the ether for optical as well as for electrical phenomena, and explain them also on the ideas of lines of force? Let me quote Dr. Campbell's answer to this question.

"We can; and it is possible to explain optical phenomena in terms of the properties attributed to the lines of force, just in the same way as we explained the phenomena of electric currents in terms of the properties of the fluid electricity.[26] . . . If we are to have an electrical theory of light [which all proponents of the ether accept], we must show that this conception is applicable to the theory of electricity.

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[25] Campbell, Norman R., "Principles of Electricity," Pages 76-77, Little Blue Book No. 133.

[26] Dr. Campbell, of course, refers here to the now-abandoned "fluid theory of electricity" only for purposes of illustration and comparison.

. . . The properties which we have attributed to lines of force lead to the conclusion that waves might travel along them; can these waves be identified with those of light?"[27]

Dr. Campbell's answer is "Yes." And Dr. Steinmetz was no less fully convinced that there existed no grounds for assuming the existence of an ether filling all space and interpenetrating all matter. Hence there is no reason for supposing that electrons are modifications of this purely hypothetical ether, or that this assumed phenomenon is the source and seat of all energy.

"Electrophysics," says Dr. Steinmetz,[28] "has been successfully developed to its present high state, and has dealt with alternating currents, voltages and electromagnetic fields, without ever requiring or considering a medium such as the ether. Whatever may be the mechanism of the electro-magnetic wave, it certainly is not a mere traverse wave motion of matter, and the light, being shown to be a high-frequency electromagnetic wave, cannot be considered any more as a wave of motion of the ether. The ether thus vanishes, following the phlogiston and other antiquated physical conceptions. The conception of the field of force, or, as we should more correctly say, the field of energy, thus takes the place of the conception of action at a distance and of the ether. The beam of light and the electromagnetic wave (like that of the radio communication station or that surrounding a power transmission line) are therefore periodic alternations of the electromagnetic energy field in space, and the differences are merely those due to the differences of frequency.....Energy is the only real existing entity, the primary conception, which exists for us because our senses respond to it."

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[27] For a most interesting discussion of this problem see the booklet previously mentioned, Pages 73-87.

[28] "Relativity and Space," Pages 21-22, New York, 1923.

"It may even happen," says Dr. O. W. Richardson, Whetstone Professor of Physics at King's College (London), "that it is impossible to form a consistent scheme of electromagnetic phenomena, without discarding the idea of a medium altogether."[29]

"There is no experimental evidence of any optical effects arising from the motion of matter relative to ether or to space," he says on

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[29] Richardson, Prof. O. W., The Electron Theory of Matter," Page 268, Cambridge University Press, 1914.

Page 284 of the same work. "One is therefore tempted to inquire whether it is really necessary to postulate an ether for the propagation of optical and electrical effects; it may appear that a more consistent set of relations would be obtained solely by the relative motion of matter."

Obviously, if the postulated ether of our text-books does not exist, it would be a waste of time to discuss the problem of how electrons can be derived from it by strains, condensations, "knots," vortices, "gyrons," etc. The only "ether" that can be demonstrated to exist is the electromagnetic field of force or of energy—stored-up energy—"a condition of energy storage in space exerting a force on a body susceptible to this energy."

ELECTRICITY AND ETHER

There is nothing new in the view that the ether, or plenum, is electrical in nature. This view was long ago (1846) proposed by the German physicist, W. E. Weber (1804-1891), who, in discussing Faraday's epoch-making discoveries, in the first part of his researches in magnetism and electricity, suggested that the "all-pervading neutral electric [intervening] medium [between two interacting electrical particles] itself constitutes the all-pervading ether which contains and propagates luminous waves." This was also the view of the American physicist Joseph Henry (1797-1878) and some later authorities.[30]

Dr. J. H. Jeans, one of the greatest living mathematical physicists, is in agreement with other high authorities in concluding that neither optical nor electrical phenomena even imply the existence of an ether. Certain it is that its existence has not been detected by any of the most delicate tests to which the problem has been subjected.

However, there are comparatively few physicists today who are willing to abandon the idea of a universal ether. They regard this indescribable plenum not only as the medium in which electromagnetic waves are propagated, but also as the seat of all energy and all that is. All attraction and repulsion of electrons and atoms, they assume, is brought about through the mediumship of the ether.

THE ARGUMENT FOR AN ETHER SUMMARIZED

Sir Oliver Lodge has frequently expressed his conviction that the ether and electrons are very closely related; for they attract and repel each other. "That is to say, there is a strong mutual force urging electrons and protons together, and at the same time keeping apart the units of the same kind"; and this force, he contends, whether of attraction or repulsion, must necessarily be exerted through and by means of the intervening ether.

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[30] It is interesting to note that the now classical ether theory was opposed by Auguste Compte (1795-1857), John Stuart Mill (1806-1873) and Sir David Brewster (1781-1868).

"Furthermore, we know that when ether is in motion it is surrounded by a magnetic field, which magnetic field consists of some modification in the ether, and extends a considerable distance round the moving nucleus or kernel. These facts are commonly expressed by saying that a moving charge has two fields of force; one, radiating from it in all directions, is called its electric field; while the other, which surrounds its line of motion in rings—opening out more and more of them and crowding them closer together as the motion increases in speed—is called its magnetic field. It is this last which confers upon each unit its fundamental property of inertia; that is, its power of persisting in motion until it is disturbed—checked, hastened or deflected—by some external force."[31]

On this view of the constitution of matter, to quote that eminent authority, Sir Joseph

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[31] *Loc. cit.*, Page 308.

Thomson, "part of the mass of any body would be the mass of the ether dragged along by the Faraday tubes [lines of force] stretching across the atom between the positively and negatively electrified constituents....The whole mass of any body is just the mass of ether surrounding the body which is carried along by the Faraday tubes, associated with the atoms of the body....All mass is mass of the ether, all momentum, momentum of the ether, and all kinetic energy, kinetic energy of the ether. This view, it should be said, requires the density of the ether to be immensely greater than that of any known substance."

We are told by many eminent physicists that the "ether" is the one and only "real solid" in the universe; yet through this ocean of immaterial material — "somehow consistent with itself"—the planets and suns (stars) roll with velocities ranging from three to hundreds of miles a second. And the ether remains virtually undisturbed; because what we call matter is, says Sir J. J. Thomson, "the least substantial thing in the world." Physicists assure us that the unresisted passage of matter through the ether is easily explained, since "matter is composed mainly of holes," possessing a bird-cage kind of structure. Each mass of iron, lead, stone, wood, etc., is composed of comparatively widely separated molecules; these in turn are made up of atoms distributed at wide intervals, as at the cross-sections of a lattice framework in three dimensions. The atoms, in turn, are composed of the far more minute electrons, which revolve, perhaps, within the sphere of action of the atoms much as planets revolve in our solar system. The atoms move through the ether without disturbing its placidity, just as our solar system moves onward, unresisted, through the same medium, at a velocity of twelve and a half miles a second, toward a point near the borders of the constellations Lyra and Hercules.

Sir Oliver Lodge pictures the ether as a complicated structure somewhat similar to the mechanic's interlocking geared wheels, in order to account for electromagnetic action. He tells us that "the ether is the most massive thing in the world." Yet it is assumed to be some 700,000 times more elastic than air!

Out of this apparently paradoxical "medium," say a number of our foremost men of science, electrons are made, and out of electrons everything else is made. The sunlight is emitted by electrons, the chair we sit upon is a congeries of electrons—trillions of them; —we ourselves are composed of electrons, as are the earth, air, water, the planets, comets and far distant stars. Yet, in themselves, they reveal themselves to man's intelligence only as bodiless "point charges" of negative electricity, arising as "singularities" in the ether, or, according to Professor Parsons, as electric rings. The late Professor Duncan stated that electrons are not particles of matter possessing the properties of negative electricity, but, instead, are "corpuscles of negative electricity possessing the properties of matter." So that when we sit in our chairs we are resting on particles of negative electricity, bound together by positively charged nuclei in the guise of matter!

The famous chemist, Prof. William Ostwald, went so far as to declare that there is "not the slightest bit of evidence that matter exists. What we know is *energy* and matter is a pure hypothesis, created out of the imagination to have something to which to attach energy."

XI.

MASS AND VELOCITY

In 1881, as previously stated, Prof. J. J. Thomson demonstrated that an electrical charge possesses inertia, or mass.

The celebrated mathematical physicist, Prof. Max Abraham, was among the first investigators to ask himself whether the electron actually contained any matter at all, whether its apparent mass might not be entirely due to its "wake," a question he subjected to mathematical analysis, with affirmative results. Its mass, on this hypothesis, should increase with increasing velocity.

Kaufmann was the first physicist (1906)[32] to prove experimentally that, as a matter of fact, the apparent mass of electrons increases rapidly as velocities of 300,000 kilometers per second are approached, as shown by the figures below:

If 1 represents the mass of the corpuscle at low speed, the apparent mass measured is as follows:

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[32] *Goett, Nachr.*, 1901, Vol. 1; 1902, Vol. 5; 1903, Vol. 3; *Phys. Zeit*, Page 55, 1902; *Ann. der Phys.* IV. VOL. XIX, Page 487, 1906. In the last-named journal a complete account is given of Kaufmann's experiments, perfected in 1906. See also an account of Bucherer's experiment to test the different theories of the constitution of the electron, *Ann. der Phy.*, IV, Vol. XXVIII, Page 513, 1909.

For speed of 220,000 kilometers per second 1.32
For speed of 240,000 kilometers per second 1.53
For speed of 260,000 kilometers per second 1.78
For speed of 288,000 kilometers per second 2.44
For speed of 297,000 kilometers per second 3.16

The meaning of the foregoing figures, as also the conception of *mass* in terms of *energy*, may be more readily grasped in the light of the following clear statement from Soddy's well known work on "Matter and Energy" (1912):

"When an electron is being urged on to move from rest at a continually increasing speed, surrounding its path there is being built up, as the expression goes, a magnetic field of greater strength. The energy being put into the electron, overcoming its inertia, flows out continuously into space surrounding its path and travels along with it. When the electron is being retarded and brought to rest, the energy it, itself, is now supplying, by virtue of its inertia, flows in from the surrounding space and the magnetic field gradually weakens and disappears. As we know that the magnetic field extends for a considerable distance all round an electro-magnet, these outgoings and incomings of energy, between the electron and its environment, involve the transference of energy over considerable distances, and as the air or surrounding matter plays no part in the phenomena, they must take place through empty space. It is not too much to say that the idea of an ether has been invented by scientific men for the express purpose of accounting for the flow of energy across empty space, and is at present little more than a term to express the medium in which these transferences occur."

Professor Soddy thinks, however, that the ether is not "purely a philosophical way to escape from the unknown," since, he observes, it has "at least one very definite characteristic, *which is quite sufficient to entitle it to be considered as a physical reality*," (italics mine); namely, it "transmits light and so far as is known, every other influence which traverses it, at a definite speed—186,000 miles in a second. This velocity is as characteristic of it as the velocity of sound in air, 1,200 feet per second, is characteristic of the atmosphere."

As to whether there is or is not an ether that "transmits light" and "every other influence which traverses it," this is a question on which the doctors of science are not agreed. It is quite true that the electromagnetic (Hertzian) waves have the same velocity of propagation as light waves. But Maxwell deduced mathematically and Hertz demonstrated experimentally that electromagnetic waves and (polarized) light waves "are identical in all their properties." Hence, as the lamented Dr. Steinmetz declared a few months before his death, light is an electromagnetic wave,—i. e., an alternating electromagnetic field of extremely high frequency, and *not* a wave motion of *an ether*.

MATTER AND ENERGY ELECTRONIC

The "electron," like the hypothetical all-pervasive "ether," was at first a pure mathematical invention, an hypothesis called into being in order to account for certain otherwise inexplicable electromagnetic phenomena. One example will suffice for our present purposes.

It was well known that the same magnetic force produces a strong effect on iron and none on copper. Bring a piece of iron close to a permanent bar magnet, and it will be seen to move toward the magnet. Now place a piece of copper close to the magnet. Nothing happens. The magnetic field of force still surrounds the magnet, but the copper is not susceptible to it. A piece of iron interposed between the magnet and the first piece of iron increases the force of the attraction. A copper plate placed in the same position has no effect—unless it is revolved (but this is another story).

Now, these different effects could be satisfactorily accounted for only by the creation of an hypothesis which would explain their mechanism and behavior. Professor Lorentz therefore assumed that the observed difference of behavior could be explained by supposing that there existed in all ponderable bodies extremely small electrical (charged) particles, or corpuscles (electrons).

These electrons were assumed to be of two kinds, the charge of some being positive, of others negative, and they were supposed to be free to traverse conductors of electricity, and on the other hand, to be bound to "points of equilibrium" in non-conductors.

Lorentz rightly regarded the inertia, or mass, of these corpuscles as due mainly to their electric charge.

Dr. Hugh Elliot thinks there should be no great difficulty in thinking of matter in terms of energy, since all form of radiant forces are at once very real and quite immaterial, on the commonly accepted electromagnetic theory. Says he:

"The tendency of recent physical science is to obliterate the distinction between matter and energy. The universe no longer seems to be occupied by two fundamentally different forms of existence. It is simply the seat of electrons, which give rise to what we know as matter and energy, manifesting themselves in a great variety of different forms. True, we still have a dualism at the root of all phenomena. If it is no longer the dualism of matter and energy, it is that of positive and negative electricity. But the contrast between these two is far more easily bridged by the mind than the contrast between matter and energy. They are the same *kind* of existence; the same laws apply equally to both; their effects upon the neutral environment are in all cases identical. We have approached, by this doctrine, far nearer to the complete unification of knowledge, which has long been the goal of philosophy."

On the other hand, Mr. Marion Erwin, in his thought-provoking work, "The Universe and the Atom", takes exception to the use of the word "electricity" as "the ultimate thing in nature". "Electricity," he observes, "is a compound idea, a *particular* form of energy. To stop our explanations at the electron, call it 'electricity', and treat it as the ultimate thing, leaves us but a little better off than were our early scientists who explained fire by the escape of 'phlogiston' from matter."

THE "QUANTEL" OF LANGMUIR

At the concluding session of the National Academy of Sciences, in 1920 (Washington, D. C.), Dr. Irving Langmuir advanced a new theory of the structure of the ether, electricity, magnetism, energy, time and space. Heretofore matter has been successively subdivided into molecules, atoms and electrons. Dr. Langmuir now proposes a still smaller and more elemental entity, namely, the "quantel", consisting of two parts, positive and negative, present everywhere, moving in all directions with the velocity of light, and capable of passing through solid substances. The "quantel" constitutes the so-called ether of space, and is the cause of the phenomena of light, heat, electricity, gravitation; in short, all manifestations of energy.

Space and time, he said, have a structure analogous to that of matter. Doubtless Dr. Einstein will not feel so lonely hereafter!

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278 Friendship, and Other Essays. Thoreau.
448 Essays on Montaigne, Pascal and Voltaire. Powys.
449 Essays on Rousseau, Balzac and Hugo. Powys.
450 Essays on De Maupassant, Anatole France and William Blake. Powys.
451 Essays on Remy de Gourmont and Byron. Powys.
452 Essays on Emily Bronte and Henry James. Powys.
453 Essays on Joseph Conrad and Oscar Wilde. Powys.
460 Miscellaneous Essays. Haldeman-Julius.
461 Literary Essays. Haldeman-Julius.
534 Honey and Gall. Powys.

Fiction

21 Carmen. Merimee.
23 Great Stories of the Sea. Cooper, Loti and Marryat.
29 Dreams. Schreiner.
37 Dream of John Ball. Morris.
352 XIIIth Century Prose Tales. Morris.
40 The House and the Brain. Lytton.
41 A Christmas Carol. Dickens.
53 Tales from the Decameron. Boccaccio.
72 The Color of Life. Haldeman-Julius.
102 Sherlock Holmes Tales. Doyle.
107 The Dream Woman. Collins.
145 Great Ghost Stories.
148 The Strength of the Strong. London.
151 The Man Who Would Be King. Kipling.

331 The Finest Story in the
332 The Man Who Was, and Other Stories. Kipling.
333 Mulvaney Stories. Kipling.
336 The Mark of the Beast. Kipling.
357 City of the Dreadful Night. Kipling.
161 The Country of the Blind. Wells.
182 Daisy Miller. James.
307 A Tillyloss Scandal. Barrie.
215 The Miraculous Revenge. Shaw.
232 The Three Strangers. Hardy.
277 The Man Without a Country. Hale.
285 Euphorian in Texas. Moore.
355 Aucassin and Nicolete. Lang.
363 Miggles and Other Stories. Harte.
397 Irish Fairy Tales.
420 Short Stories from the Spanish.
454 The Unworthy Coopers, etc. Haldeman-Julius.
334 Caught and Other Stories. Haldeman-Julius.
489 Great Yiddish Short Stories. Edited by Goldberg.
577 The Lifted Veil. Eliot.
583-584-585-586-587-588 The Jungle. 6 Vols. Sinclair.
590-591-592 The Millennium. 3 Vols. Sinclair.
594 The Overman Sinclair.
595 The Happy Hypocrite. Beerbohm.

Fine Arts

476 A Handbook on the Gilbert and Sullivan Operas. Goldberg.
287 Whistler: The Man and His Work.
387 History of Painting. Sheehan.
403 History of Music. Sheehan.
466 A History of Sculpture. Sheehan.
468 A History of Architecture. Sheehan.
413 The Need for Art in Life. Holborn.
507 Richard Wagner: An Introduction. Goldberg.

(Note: In the operatic titles listed below, Mr. Theo. M. R. von Keler gives short biographical sketches, the story of the opera and helpful criticism of the music, illustrated by excerpts from the score.)

410 Die Walkuere. Wagner.
440 Cavalleria Rusticana. Mascagni.
441 I Pagliacci. Leoncavallo.
455 Richard Strauss's Salome.
456 Carmen. Bizet.
457 Lohengrin. Wagner.
458 Tannhauser. Wagner.
459 Das Rheingold. Wagner.
494 Siegfried. Wagner.
495 Rigoletto. Verdi.
569 Gotterdammerung. Wagner.

History

50 Paine's Common Sense.
34 The Mystery of the Iron Mask. Von Keler.
67 Church History. Tichenor.
83 Marriage: Its Past, Present and Future. Besant.
125 War Speeches of Woodrow Wilson. Edited by Smith.
126 History of Rome. Giles.
149 Historic Crimes and Criminals. Finger.
150 Lost Civilizations. Finger.
169 Voices From the Past. Tichenor.
174 Trial of William Penn.
185 History of Printing. Disraeli.
201 Satan and the Saints. Tichenor.
214 Speeches of Lincoln.
276 Speeches and Letters of George Washington.
286 When the Puritans Were in Power. Tichenor.
469 The Egypt of Yesterday: A History of Exploring and Excavation. Moritzen.
5[illegible] A History of Polar Exploration and Adventure. Van Sicklen.

509 The Ancient Regime (France Before the Revolution). Gottschalk.
515 The Fall of Louis XVI. Gottschalk.
558 Great Pirates. Finger.
275 Science of History. Froude.
596 A History of Modern Mexico. Parker.

French Literature (In English)

15 The Atheist's Mass, and An Accursed House. Balzac.
143 In the Time of Terror, and Other Stories. Balzac.
318 Christ in Flanders, and Other Stories. Balzac.
344 Don Juan, and A Passion in the Desert. Balzac.
237 Poems in Prose. Baudelaire.
665 Sarah Bernhardt's Love Letters to Sardou.
314 Short Stories. Daudet.
6 Love, and Other Stories. Maupassant.
199 The Tallow Ball (Boule de Suif) Maupassant.
292 Mademoiselle Fifi, and Other Stories. Maupassant.
66 Crimes of the Borgias. Dumas. (Edited by H. M. Tichenor).
300 Terrorism in France. Dumas.
319 Comtesse de Saint-Geran. Dumas.
570 The Legend of Saint Julian the Hospitaller. Flaubert.
198 The Majesty of Justice. France.
219 The Human Tragedy. France.
178 One of Cleopatra's Nights. Gautier
230 The Fleece of Gold Gautier.
345 Clarimonde. Gautier.
377 A Night in the Luxembourg. Gourmont.
540 Stories in Yellow, Black, White, Blue, Violet and Red. Gourmont. Trans. by Isaac Goldberg.
541 Stories in Green, Rose, Purple. Lilac and Orange. Gourmont. Trans. by Goldberg.
582 Philosophic Nights in Paris. Gourmont. Trans. by Goldberg.
27 Last Days of a Condemned Man. Hugo.
52 Oration on Voltaire. Hugo.
104 Battle of Waterloo. Hugo.
279 The King Enjoys Himself (Le Roi s'Amuse). Hugo.
99 Tartuffe. Moliere.
194 The Misanthrope. Moliere.
229 Les Precieuses Ridicules. Moliere.
309 The Nobody Who Apes Nobility (Le Bourgeois Gentilhomme). Moliere.
87 Love: an Essay. Montaigne.
31 Pelleas and Melisande. Maeterlinck.
221 Women, and Other Essays. Maeterlinck.
310 Life of Jesus. Renan (Condensed by H. M. Tichenor).
273 Chapters from the Social Contract. Rousseau.
238 Essays on Chesterfield and Rabelais. Sainte-Beuve.
196 The Marquise Sand.
564 Volney's Ruins of Empires. (Condensed by John Mason).
3 Eighteen Little Essays Voltaire.
28 Toleration Voltaire.
103 Pocket Theology. Voltaire.
200 The Ignorant Philosopher. Voltaire.
85 The Attack on the Mill. Zola.

Humor

18 Idle Thoughts of an Idle Fellow. Jerome.
20 Let's Laugh. Nasby.
166 English as She Is Spoke. Twain.
231 Eight Humorous Sketches. Twain.

291 The Jumping Frog, and Other Humorous Tales. Twain.
662 Amusing Answers to Correspondents. Mark Twain.
668 Humorous Fables. Mark Twain.
187 Whistler's Humor.
205 Artemus Ward, His Book.
368 To California and Back. Ward.
369 Artemus Ward's Travels.
216 Wit of Heinrich Heine. Eliot.
381 Wit and Wisdom of Dickens. Swasey.
382 Humor and Wisdom of Lincoln. Gunn.

Ibsen, Henrik

16 Ghosts.
80 Pillars of Society.
295 The Master Builder.
302 The Wild Duck.
303 Rosmersholm.
350 Hedda Gabbler.
353 A Doll's House.
354 The League of Youth.
154 Epigrams of Ibsen.
436 Henrik Ibsen: His Life, Aim and Influence. Moritzen.

Juvenile

44 Aesop's Fables.
57 Rip Van Winkle, and the Legend of Sleepy Hollow. Irving.
156 Andersen's Fairy Tales.
158 Alice in Wonderland. Carroll.
188 Surprising Adventures of Baron Munchausen. (Edited by Charles J. Finger).
391 A Dog of Flanders. Ouida.
392 The Nurnberg Stove. Ouida.
399-400 Tales from the Arabian Nights. 2 Vols.
482 Five Weeks in a Balloon. Verne. (Condensed by Charles J. Finger).
483 The Privateersman. Marryat. (Condensed by Charles J. Finger).
485 A Voyage to the Moon. (Condensed by Charles J. Finger).
516 Book of Real Adventures. Finger.
538 Robin Hood and His Merry Men. Finger.
559 Robinson Crusoe. Defoe. (Condensed by Lloyd E. Smith).
561 African Jungle Tales. Collected by C. J. Bender.

Literary Criticism

10 Essay on Shelley. Thompson.
63 A Defense of Poetry. Shelley.
109-110 Dante, and Other Waning Classics. 2 Vols. Mordell.
223 Essay on Swinburne. Quiller-Couch.
233 Thoughts on Literature and Art. Goethe.
411 A Guide to Cervantes. Goldberg.
422 Dante: An Aesthetic View. Goldberg.
431 Literary Stars on Scandinavian Firmament. Moritzen.
434 Significance of Georg Brandes. Moritzen.
435 One Hundred Best Books. Powys.
503 August Strindberg: The Literary Enigma. Moritzen.
519 A Guide to Rabelais. Goldberg.
529 Walt Whitman: Bard of the West. Hamblen.
530 Camoens: Central Figure of Portuguese Literature. Goldberg.
531 A Guide to Georg Brandes's "Main Currents in 19th Century Literature." Moritzen.

Literature

7 A Liberal Education. Huxley.
17 On Walking. Thoreau.

26 On Going to Church. Shaw.
135 Socialism for Millionaires. Shaw.
84 Love Letters of a Portuguese Nun.
89 Love Letters of Men and Women of Genius.
95 Confessions of an Opium Eater. De Quincey. (Edited by Lloyd E. Smith).
97 Love Letters of King Henry VIII.
177 Subjection of Women. Mill.
194 Lord Chesterfield's Letters.
195 Thoughts on Nature. Thoreau.
213 Lecture on Lincoln. Ingersoll.
225 On a Certain Condescension in Foreigners. Lowell.
289 Pepys' Diary. (Edited, with Foreword, by Charles J. Finger).
299 Prose Nature Notes. Whitman.
305 Machiavelli. Macaulay.
367 Essay on Conversation. De Quincey.
472 The Strange Notes of Samuel Butler. (Edited by John W. Gunn).
487 Carlyle's Philosophy of Clothes. (Based on "Sartor Resartus.") Smith.
513 The Travels of Marco Polo. Finger.

Literature (Ancient)

316 Prometheus Bound. Aeschylus.
418 The Bacchantes. Euripides. Trans. by Alexander Harvey.
500 Medea. Euripides. Trans. by Alexander Harvey.
502 Hippolytus. Euripides. Trans. by Alexander Harvey.
560 Electra. Euripides. Trans. by Alexander Harvey.
511 King Oedipus. Sophocles. Trans. by Alexander Harvey.
562 Antigone. Sophocles. Trans. by Alexander Harvey.
473 Essays on Euripides. Harvey.
474 Essays on Sophocles. Harvey.
475 Essays on Aeschylus. Harvey.
497 Legends of Greek and Roman Heroes. Smith.
498 Greek and Roman Mythology. Smith.
499 A Dictionary of Classical Mythology. Smith.
479 Proverbs of Germany. (Collected by Julius Moritzen).
365-366 The Odes of Horace. 2 Vols.
527 A Guide to Aeschylus. Schnittkind.
163 Sex Life in Greece and Rome. Dickenson.
167 Rules of Health. Plutarch.
581 Lucretius on Life and Death. Trans. by W. H. Mallock.

Maxims and Epigrams

35 Maxims of La Rochefoucauld.
56 The Wisdom of Ingersoll.
59 Epigrams of Wit and Wisdom.
77 What Great Men Have Said About Women. (Shakespeare, Milton, Tennyson, Hugo, Ruskin, Browning, Byron, Scott, Thackeray, Carlyle, Wordsworth).
106 Aphorisms of George Sand.
113 Proverbs of England.
114 Proverbs of France.
115 Proverbs of Japan.
116 Proverbs of China.
117 Proverbs of Italy.
118 Proverbs of Russia.
119 Proverbs of Ireland.
120 Proverbs of Spain.
121 Proverbs of Arabia.
348 Proverbs of Scotland.
380 Proverbs of Jugoslavia. (Collected by Louis Adamic).
388 Proverbs of Hindustan. (Collected by Champak C. Shah).
401 Proverbs of India. (Collected by Champak C. Shah).
478 Sanskrit Proverbs. (Collected by Champak C. Shah).